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Spartial and Seasonal Variations in Concentrations of Polycyclic Aromatic Hydrocarbons in Water and Sediment of Kisumu City Bay of Winam Gulf, Lake Victoria-Kenya

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Abstract Seasonal and offshore concentration variations for selected sixteen priority pollutant polycyclic aromatic hydrocarbons (PAHs) in surface sediments and water of Car Wash and Kisat areas of Winam Gulf, Lake Victoria, have been investigated. PAHs concentrations in sediments and water range from 0.4 to 31.95 µg/g dry weight and 3.32 to 55.8 µg/L, respectively. Statistical analysis of the PAHs concentrations showed that the most contaminated samples are found during rainy season (April, 2006), 5 m offshore for sediments and 10 m offshore for water. Dry season (October, 2005) generally recorded lower concentrations. The variations showed significant difference ($p \leq 0.05$) with season and distance of sampling from the shore.

Keywords PAHs · Sediment · Pollution · Kisat · Car wash · Lake Victoria

Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a typical class of persistent organic compounds derived from natural sources including forest fires or/and anthropogenic processes such as urban and industrial activities, are ubiquitous in the environment and recalcitrant to biodegradation. Sixteen PAHs have been recommended as priority pollutants by the United States Environmental Protection Agency (USEPA) because of their carcinogenicity, mutagenicity, and toxicity (McVeety and Hites 1988). PAHs are introduced into the environment through riverine discharge and/or long-range atmospheric transport and subsequent dry/wet deposition (McVeety and Hites 1988). Due to their hydrophobia character, once introduced into the environment, they rapidly become associated with suspended particles and hence bottom sediments (Readman et al. 1984). Contemporary sediments are considered as a 'sink' for hydrocarbons in the aquatic environment and their importance in pollution monitoring has been emphasized by many authors (Wakeham 1980). Sediments are a good source of samples exhibiting levels of hydrocarbons several magnitudes higher than those found in the water column. Moreover, they are relatively easy to sample and to store and can be studied at different depths (Witt 1995). Sediment retention capacity for PAHs can be related to their Physico-chemical properties such as organic carbon content, grain-size and retention of diagenesis (Yunker et al. 1996; Baumard et al. 1998). The origin of PAHs influences their accumulation and distribution in the sediments (Hostettler et al. 1999).

Lake Victoria is situated at 0°21′N-3°0′S, 31°39′-34°53′E astride the equator on an altitude of 1,240 m above sea level with a surface area of 68,800 sq. km (Ogutu-Ohwayo et al. 2002). Kisumu City is situated at 0°6′S, 34°45′N on the North tip of the Winam Gulf, which is part of the Kavirondo Gulf of the Lake Victoria (Fig. 2). It is the third largest city in Kenya as well as the principal port of the lake on the Kenyan side. It has a population of 322,724 according to 1999 population census. In the recent past, Jua-Kali sector (small holder industries) has received great attention from the government and donor countries and has rapidly expanded. By 1996, the registered Kisumu Jua-kali association had a

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membership of 10,000 operating about 10,000 working spaces in the town with the major activity of repairing diesel injectors, major vehicle overhaul, panel beating and spraying of motor vehicles (David and Nancy 1995). Next to these garages are small-scale mechanics dealing with minor vehicle mechanical problems. These garages contribute to an estimated total load of used oil to the lake of 182,500 L oil per year (David and Nancy 1995), making the pollution situation described above more serious. Washing of vehicles on the pavements of streets and in the lake, which started in 1960, has also recently increased as a commercial activity, discharging oil spills directly into the open Gulf waters. Railway wagons and tankers transporting oil to the depots are cleaned on site and the railway harbour, which started operating in 1901, occasionally causes localized oil spills from the fuelling points. The oil and diesel spills after servicing of the trains and ships contribute to localized pollution around the Kisumu bay. The fuel storage tanks are washed once every 5–10 years and the resultant water dumped into drains. Car washing, including engine wash, spill approximately 51,200 L of oil per year for an average 200 cars per day (David and Nancy 1995).

This study was undertaken to establish the distribution of the sixteen USEPA priority pollutant PAHs in sediment and water samples drawn from Winam gulf of Lake Victoria in Kenya and determine any fluctuations in their concentrations with seasonal changes and changes in distance of sampling offshore. The PAHs considered are; acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)-perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene and pyrene (IARC 1983).

Materials and Methods

Water and sediment sampling was done from the two sampling sites, Kisat and Car Wash, both of which are found within the Winam Gulf of Lake Victoria, Kenya (Fig. 1). Three replicate samples for sediment and water taken from each of the sampling sites. Sediment sampling was done using a pre-cleaned sediment grab sampler at about 1 m from the shore. The ca. 200 g samples were kept in pre-cleaned 250 mL sample jars with lids lined with aluminium foil and kept in a cooling box with dry ice. Water sampling was done using a pre-cleaned undersurface water sampler about 5 m offshore and 1 m below the surface. The water samples were kept in pre-cleaned amber coloured 2.5 L glass bottles. The samples were then transported and kept at 4°C awaiting extraction.

A 50 g mass of each sediment sample was Soxhlet extracted with 250 mL of the double distilled methanol (CH_3OH) for 4 h at a fill-empty rate of 2 cycles/h. The extract was then allowed to cool for 30 min and 25 mL of 0.7 N KOH added. The resultant mixture was further refluxed for 2 h (UNEP 1992). The KOH/CH_3OH mixture was then poured into a glass separating funnel with a glass stop cork. The extraction glass was rinsed with two aliquots of hexane totaling to 50 mL and the washings added to the separating funnel. The funnel was tightly stoppered and shaken vigorously for 5 min carefully venting vapours out of the inverted funnel periodically, through the tap. The mixture was then clamped on a retort stand and phases allowed to separate. The hexane top layer was then removed and filtered through anhydrous Na_2SO_4 in a Buckner funnel under suction pump and further rinsed with hexane aliquots totaling 20 mL. This layer was the non-saponifiable lipid (NSL) fraction containing the non-volatile hydrocarbons (UNEP 1992).

The hexane layer was concentrated to ca. 5 mL in a rotary evaporator under an aspirator pump with bath temperature kept at 40°C. This was kept in a deep freezer at − 4°C awaiting column purification. Purification was done through a 2 cm i.d glass chromatograph column packed with 8 g of deactivated silica gel with Na_2SO_4 added to a height of 2 cm. Two 1 mL aliquots of hexane were used to wash the extract onto the silica gel. The PAHs were subsequently eluted with 15 mL hexane and then 25 mL of 1:1 (V:V) hexane:dichloromethane mixture. The first 8 mL containing a large amount of aliphatic material was discarded (Simpson et al. 1995). The next eluent containing the analytes was then collected and concentrated under reduced pressure in a rotary evaporator to ca. 5 mL, then 2 mL of toluene added as keeper (Simpson et al. 1995), this was further concentrated in a rotary evaporator to remove any traces of hexane and dichloromethane The final product was then pipetted into a glass vial and the flask rinsed twice with 1 mL washings of toluene and the rinsings added to the sample vial. The samples were then kept in a deep freezer at −4°C for 4 days awaiting GC-FID analysis.

One litre of water sample was put in a 5 L conical flask lagged with aluminium foil and shaken with 250 mL Dichloromethane on an orbital shaker (SO1 Stuart Scientific model) for 6 h at 250 rpm (UNEP 1992). This was then allowed to settle and the lower dichloromethane layer separated in a 500 mL separating funnel. The resultant emulsion layer was removed by filtering through a funnel stacked with glass wool. The dichloromethane was then shaken with 50 g anhydrous Na_2SO_4 and further filtered through glass-wool in Buckner funnel (500 mL) under a suction pump. The resultant extract was then concentrated in a rotary evaporator under a suction pump to ca. 5 mL and kept in a deep freezer at −4°C before column purification was done. Column purification followed the same procedure as for the sediment samples.

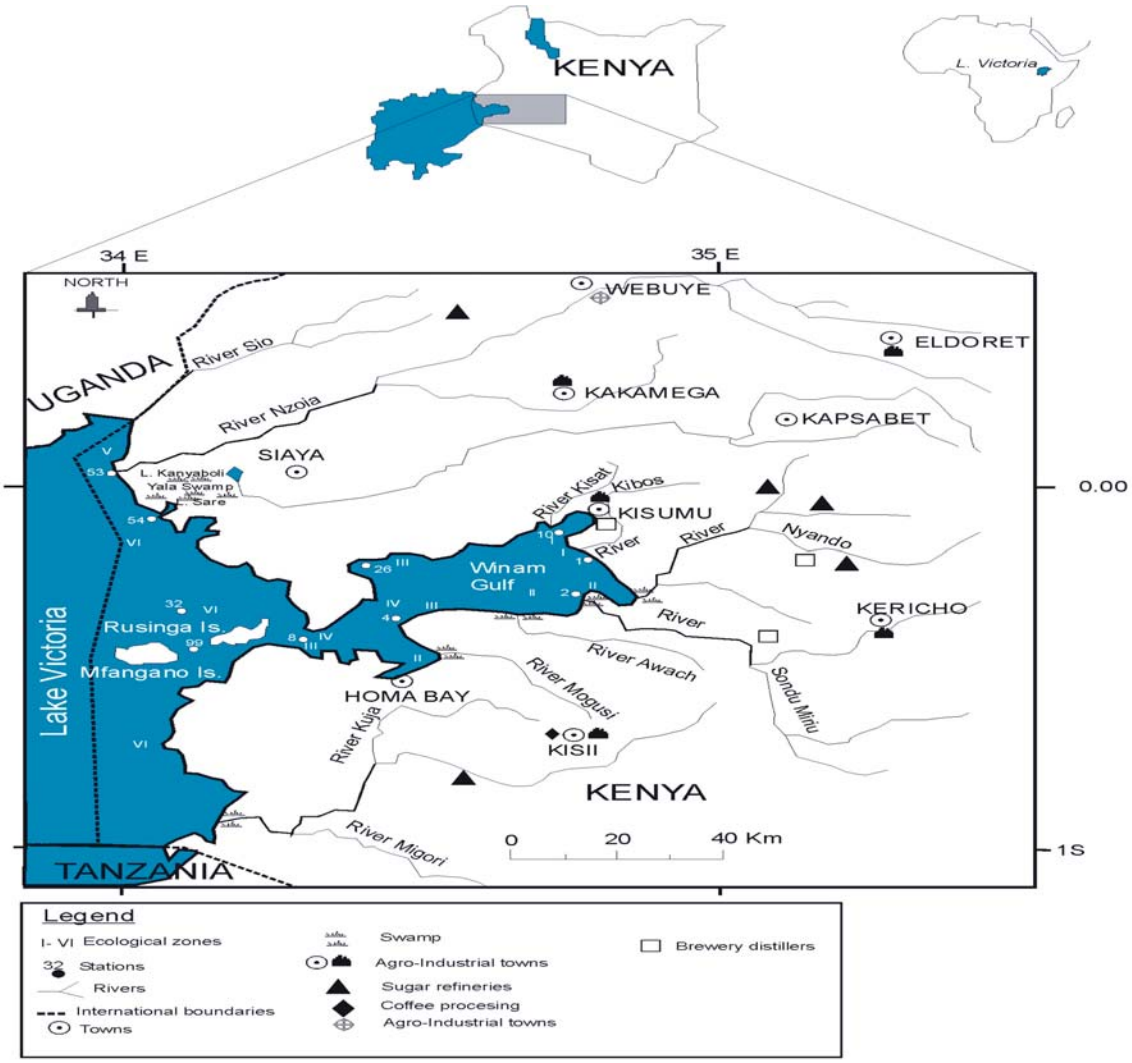

Fig. 1 Showing Kisumu City located at the shore of Winam Gulf, Lake Victoria

The PAHs were analyzed by a GC-17A Ver. 3 SHIMADZU using DB-17 capillary column (length, 30.0 m; Internal diameter, 0.25) with Flame Ionization Detector (FID) with detection limit of 10^{-6} µL. The instrument conditions were as follows: sample size, 5 µL; detector temperature, 310°C; flow pressure, 77.0 kPa; total flow, 3 mL/min; column flow, 0.83 mL/min; split ratio, 2; injection mode, splitless; injector temperature, 250°C; carrier gas, N_2; column oven programme, 60.0°C for 1 min, 180°C—rate 3.0 for 2 min, 250.0°C—rate 5.0 for 2 min.

The GC-FID analysis was done for all the samples, HPLC grade *n*-hexane (solvent blank), standard mix-9 and surrogate standard. In the GC-FID analysis, *n*-hexane solvent blank was first injected into the machine and and its chromatogram obtained. This was followed by an injection of the external standard mix 9, them by the injection of the samples. Surrogate standard (9,10-dihydroanthracene) was then injected to help in the calculation of the recovery percentages. Peak areas were computed using the standards. GC–MS was used to verify if the compounds detected in the GC-FID were the actual PAHs. The instrument conditions were as follows: Carrier gas, N; Capillary column, DB-5, i.d 0.25 mm; injector temperature, 280°C, splitless; Initial oven temperature, 50°C; final temperature, 320°C; sample injection, 5 L; programme rate, 4–6°C/min. The GC–MS retention times were quite comparable with those of GC-FID for the standard mix 9 and the samples used.

Results and Discussion

The recovery of surrogate standard ranged between 71 and 78% showing that the extraction and purification processes did not waste significant amounts of the analytes (UNEP 1992). Sediment samples were found to contain relatively higher concentrations of PAH than water samples

(Tables 1, 2, 3). This is consistent with the documented observation that the concentrations of individual PAH in sediment generally occur one order of magnitude higher than those in precipitation (WHO 1998). Vertical fluxes through the water column are also significantly accelerated in waters by adsorption of both soluble and particulate organic residues into fast sinking fecal materials generated by the zooplankton communities. This phenomenon permits the rapid settling of organic contaminants out of the surface waters and into the sediments (Readman et al. 1984). The higher concentrations in the sediment samples compared to water samples, was therefore consistent with these earlier reported observations.

The mean concentrations were found to exhibit significant differences ($p \leq 0.05$) with seasons and depths, although the degree of significance could not be established

Table 1 The mean amounts of identified PAH (μg/g) in car wash sediment sample

PAH	Dry season		Wet season	
	1 m	5 m	1 m	5 m
Naphthalene	4.72 ± 0.30	6.87 ± 1.82	6.66 ± 0.41	8.51 ± 0.43
Acenaphthylene	nd	nd	nd	nd
Acenaphthene	0.86 ± 0.07	0.93 ± 0.12	0.84 ± 0.04	1.57 ± 0.07
Fluorene	nd	nd	0.04 ± 0.06	nd
Phenanthrene	0.74 ± 0.04	0.75 ± 0.10	1.24 ± 0.23	2.66 ± 0.33
Anthracene	1.42 ± 0.40	1.78 ± 0.11	1.80 ± 0.01	1.76 ± 0.12
Fluoranthene	0.58 ± 0.03	0.68 ± 0.15	0.80 ± 0.04	0.90 ± 0.61
Pyrene	1.10 ± 0.12	1.08 ± 0.26	1.11 ± 0.21	1.54 ± 0.03
Benzo(a)anthracene	nd	nd	nd	nd
Chrysene	0.30 ± 0.04	0.34 ± 0.03	0.95 ± 0.06	1.55 ± 0.40
Benzo(b)fluoranthene	0.44 ± 0.02	0.54 ± 0.01	0.59 ± 0.02	1.63 ± 0.06
Benzo(k)fluoranthene	0.38 ± 0.01	0.42 ± 0.03	0.43 ± 0.03	0.71 ± 0.03
Benzo(a)pyrene	0.87 ± 0.06	1.20 ± 0.49	2.05 ± 0.11	1.05 ± 0.16
Indeno(123 cd)pyrene	2.74 ± 0.37	3.25 ± 0.24	2.88 ± 0.25	2.96 ± 0.22
Dibenzo(ah)anthracene	nd	nd	nd	nd
Benzo(ghi)perylene	1.41 ± 0.22	1.60 ± 0.06	2.47 ± 0.08	1.32 ± 0.11
ΣPAH	15.56	19.44	21.86	26.16

nd not detected, 1 and 5m refer to sampling distance from the shore. Mean values and standard deviations are rounded up to two decimal points, $n = 3$

Table 2 The mean amounts of identified PAH (μg/g) in Kisat sediment samples

PAH	Dry season		Wet season	
	1 m	5 m	1 m	5 m
Naphthalene	11.77 ± 0.83	15.13 ± 1.03	16.46 ± 1.13	15.62 ± 0.51
Acenaphthylene	5.98 ± 0.71	16.19 ± 1.40	11.39 ± 0.51	17.29 ± 0.34
Acenaphthene	4.18 ± 0.78	8.43 ± 0.29	15.10 ± 1.98	13.85 ± 1.48
Fluorene	0.81 ± 0.01	11.44 ± 0.62	13.28 ± 1.10	14.28 ± 0.36
Phenanthrene	6.98 ± 0.47	10.26 ± 0.68	8.25 ± 1.03	9.87 ± 0.08
Anthracene	10.22 ± 0.82	15.33 ± 1.39	8.57 ± 0.63	9.52 ± 1.84
Fluoranthene	0.76 ± 0.09	1.62 ± 0.47	4.37 ± 0.51	11.96 ± 0.25
Pyrene	6.39 ± 0.32	15.33 ± 0.36	9.01 ± 0.33	12.22 ± 0.65
Benzo(a)anthracene	2.81 ± 0.30	7.19 ± 0.25	3.59 ± 0.56	nd
Chrysene	2.02 ± 1.53	31.95 ± 1.13	4.21 ± 0.32	19.31 ± 0.32
Benzo(b)fluoranthene	nd	nd	0.28 ± 0.05	1.61 ± 0.15
Benzo(k)fluoranthene	nd	nd	0.27 ± 0.07	nd
Benzo(a)pyrene	1.36 ± 0.25	8.60 ± 0.44	3.40 ± 1.30	7.22 ± 0.82
Indeno(123 cd)pyrene	nd	10.53 ± 18.24	0.36 ± 0.13	nd
Dibenzo(ah)anthracene	13.51 ± 0.53	22.83 ± 0.90	16.09 ± 0.91	25.16 ± 2.57
Benzo(ghi)perylene	nd	nd	3.41 ± 0.46	3.43 ± 0.19
ΣPAH	66.79	174.83	118.04	161.34

nd not detected, 1 and 5m refer to sampling distance from the shore. Mean values and standard deviations are rounded up to two decimal points, $n = 3$

Table 3 The mean amounts of identified PAH (μg/L) in car wash water samples

PAH	Dry season		Wet season	
	5 m	10 m	5 m	10 m
Naphthalene	47.60 ± 5.10	45.26 ± 4.30	50.15 ± 1.45	55.80 ± 1.34
Acenaphthylene	15.66 ± 1.10	28.75 ± 1.14	21.84 ± 1.81	28.67 ± 1.50
Acenaphthene	9.12 ± 1.07	20.76 ± 1.11	13.07 ± 0.54	19.93 ± 0.52
Fluorene	12.08 ± 0.92	9.39 ± 0.58	10.47 ± 1.26	16.14 ± 0.72
Phenanthrene	9.82 ± 0.53	5.39 ± 0.37	3.39 ± 0.18	11.53 ± 1.12
Anthracene	6.47 ± 1.15	4.37 ± 0.66	7.60 ± 0.57	11.78 ± 0.53
Fluoranthene	nd	4.99 ± 0.54	3.53 ± 0.61	5.32 ± 0.26
Pyrene	12.68 ± 0.85	12.57 ± 0.74	11.86 ± 0.74	16.49 ± 0.82
Benzo(a)anthracene	6.58 ± 0.42	7.07 ± 0.48	9.69 ± 1.06	6.85 ± 0.11
Chrysene	5.75 ± 0.47	8.47 ± 1.11	13.87 ± 0.36	8.93 ± 1.53
Benzo(b)fluoranthene	nd	3.32 ± 1.13	4.58 ± 0.38	6.90 ± 1.26
Benzo(k)fluoranthene	9.21 ± 0.96	5.74 ± 0.70	6.82 ± 0.44	9.54 ± 0.83
Benzo(a)pyrene	15.61 ± 0.94	13.82 ± 1.04	10.16 ± 0.97	17.26 ± 0.98
Indeno(123 cd)pyrene	nd	nd	nd	nd
Dibenzo(ah)anthracene	7.25 ± 2.10	10.10 ± 0.85	7.10 ± 0.55	9.89 ± 0.11
Benzo(ghi)perylene	14.61 ± 1.17	14.19 ± 1.03	21.94 ± 1.72	15.62 ± 0.71
ΣPAH	172.44	194.19	196.07	240.65

nd not detected, 5 and 10 m refer to sampling distance from the shore. Mean values and standard deviations are rounded up to two decimal points, $n = 3$

in the cases since only two means were compared. The total amount of individual PAH detected in wet season samples was higher than those detected in dry season samples (Figs. 2, 3, 4). The total PAH concentration was found to be 172,000 ng/L in Winam Gulf which is significant especially in comparison with many other rivers in the world where concentrations are in the range of 4.00–9,400 ng/L (WHO 1998). It is important to note that the means were calculated by assuming that sample concentrations below detection limits used were zero.

There was significant difference ($p \leq 0.05$) between the mean concentrations for naphthalene, acenaphthylene, chrysene, acenaphthene, phenanthrene, anthracene, pyrene, benzo(k)flouranthene, benzo(a)pyrene and dibenzo(a,h) anthracene detected in wet and dry season Kisat sediment samples.

Car Wash samples showed significant differences ($p \leq 0.05$) for the mean concentrations of naphthalene, acenaphthylene, acenaphthene, flourene, flouranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b) fluoranthene

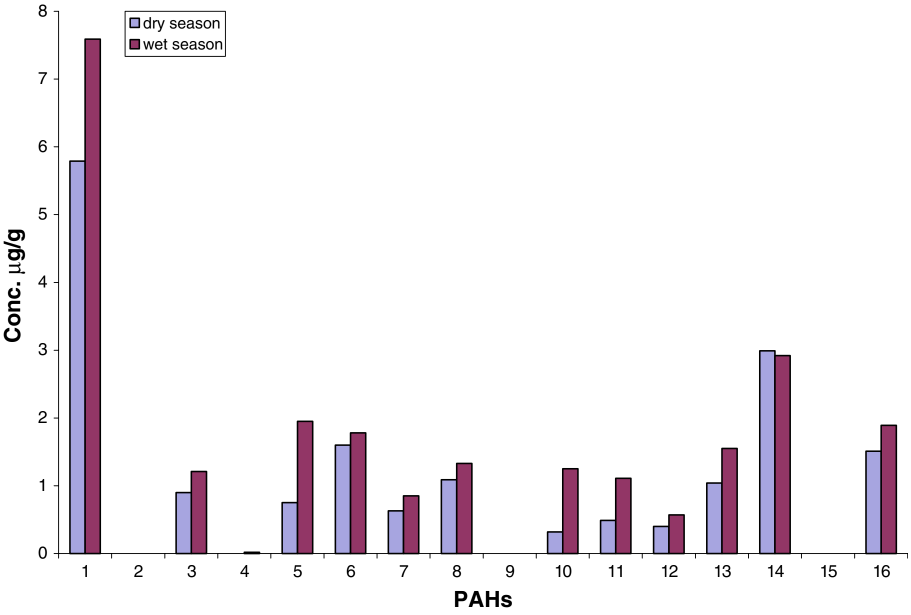

Fig. 2 Showing mean seasonal concentration variations for Car Wash sediment Samples. 1-naphthalene, 2-acenaphthylene, 3-acenaphthene, 4-fluorene, 5-phenanthrene, 6-anthracene, 7-fluoranthene, 8-pyrene, 9-benzo(a)anthracene, 10-chrysene, 11-benzo(b)fluoranthene, 12-benzo(k)fluoranthene, 13-benzo(a)pyrene, 14-indeno(1,2,3-c,d)pyrene, 15-dibenzo(a,h)anthracene, 16-benzo(g,h,i)perylene

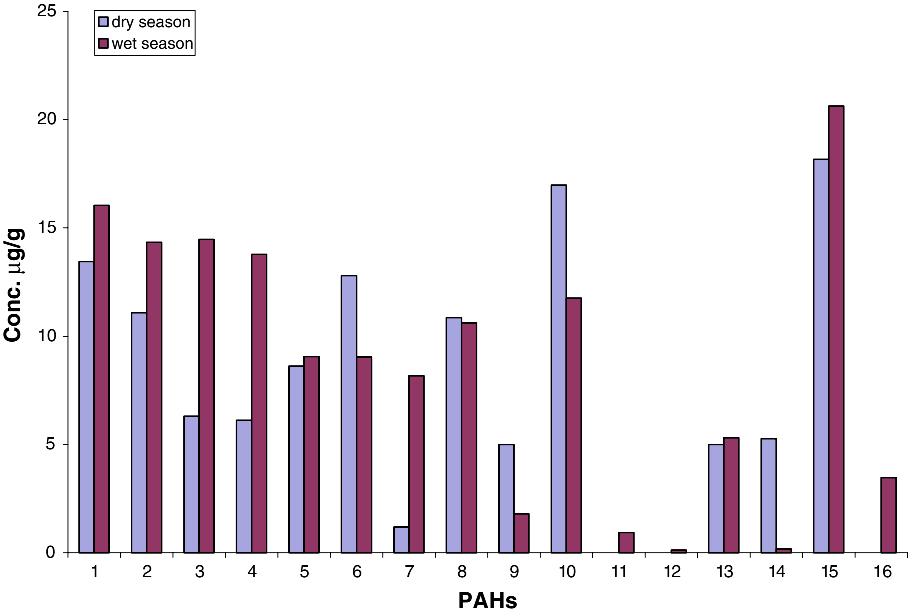

Fig. 3 Showing seasonal mean concentration variations for Kisat sediments. 1-naphthalene, 2-acenaphthylene, 3-acenaphthene, 4-fluorene, 5-phenanthrene, 6-anthracene, 7-fluoranthene, 8-pyrene, 9-benzo(a)anthracene, 10-chrysene, 11-benzo(b)fluoranthene, 12-benzo(k)fluoranthene, 13-benzo(a)pyrene, 14-indeno(1,2,3-c,d)pyrene, 15-dibenzo(a,h)anthracene, 16-benzo(g,h,i)perylene

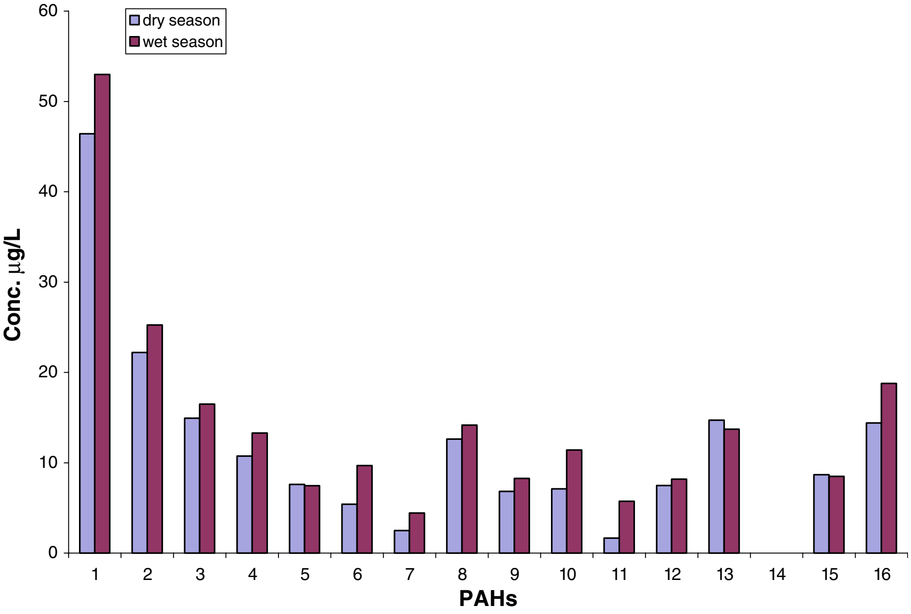

Fig. 4 Showing mean concentration variations with season for Car Wash water Samples. 1-naphthalene, 2-acenaphthylene, 3-acenaphthene, 4-fluorene, 5-phenanthrene, 6-anthracene, 7-fluoranthene, 8-pyrene, 9-benzo(a)anthracene, 10-chrysene, 11-benzo(b)fluoranthene, 12-benzo(k)fluoranthene, 13-benzo(a)pyrene, 14-indeno(1,2,3-c,d)pyrene, 15-dibenzo(a,h)anthracene, 16-benzo(g,h,i)perylene

and benzo(ghi)perylene detected in wet and dry season. This may be attributed to the fact that most of the PAH may be offloading to the gulf through surface run-off from non-point sources such as street runoff, industrial and municipal discharges in addition to the loads derived from the deposition of atmospherically transported residues of combustion and the contaminant loads associated with spills and disposal operations (Boehm 1987). Surface run-off is higher during rainy seasons and this sweeps through the city's open air garages, open incinerators and sewer systems carrying PAH adsorbed on to solid particles. This leads to higher concentrations during this season as compared to dry season when only Kisat river drains into the Gulf with less PAH pollution load. This indicates that pollution of the Gulf by PAH is mainly from non-point sources rather than point sources such as industrial spills.

The study also shows that while the sum of mean concentrations of detected PAH in sediment and water samples was notably different, the distribution of individual PAH in the samples was also different. Water samples predominantly accumulated the lower molecular weight PAH; while sediments accumulated the higher molecular weight PAH. This may be explained by the earlier reported observation that higher molecular weight PAH are primarily removed by sedimentation while lower ones through dilution and dissolution (Wakeham 1980), these lower molecular weight PAH also tend to be more soluble in water (Wakeham 1980).

The total amount of PAH detected in sediments samples taken 5 m from the shore was much higher than those detected in sediment samples taken 1 m from the shore. Similarly, the total amount of PAH detected in water samples taken 5 m from the shore was less than those detected in water samples taken 10 m from the shore. The 5 m individual PAH concentration is generally above the 1 m individual PAH concentration. These differences can be explained by the tidal disturbances and redistribution in sediment and water column along the shore (Witt 1995). There is higher tidal disturbance at 1 m distance for sediments than at 5 m distance, while for water, there is greater redistribution at 10 m distance than at 5 m distance, in addition to enhanced tidal disturbance at 5 m distance.

There were significant differences ($p \leq 0.05$) between the mean concentrations for phenanthrene, anthracene, benzo(k)flouranthene and dibenzo(ah)anthracene detected in kisat sediment samples drawn 1 and 5 m from the shore, respectively. Car wash sediment samples had significant differences ($p \leq 0.05$) for the mean concentrations of naphthalene, phenanthrene, pyrene, chrysene, benzo(a)pyrene and benzo(ghi)perylene detected in samples drawn 1 and 5 m off the shore, respectively. Similarly, the detected mean concentrations in samples drawn 5 and 10 m offshore for water samples showed significant differences ($p \leq 0.05$) for flourene, phenanthrene, anthracene, pyrene, benzo(a) anthracene, benzo(b)flouranthene, benzo(a)pyrene, dibenzo(a,h)anthracene and benzo(ghi)perylene. This observation is also supported by the fact that there is more light and dissolved oxygen at 1 m distance than 5 m distance. This provides the oxic conditions required for rapid microbial degradation of the PAH (Readman et al. 1984). In the presence of light and oxygen, PAH readily undergo photo-oxidation leading to diols, quinones, aldehydes and dimers as the metabolites. After entering the aquatic environment, organic materials can have various fates, including biological uptake, microbial degradation, volatilization, dissolution and dilution, photo oxidation and sedimentation (Readman et al. 1984; Onuska 1989). It is therefore likely that closer to the shore, where the sediments appear at a more shallow depth, most of the PAH transform into their metabolites. It was also notable that the sediments closer to the shore were coarser and silt-sized in contrast to sediments more inshore which were finer in texture. Coarser sediments support higher rates of biodegradation than fine sediments (Yunker et al. 1996; Baumard et al. 1998; WHO 1998).

The mean concentration variations with distance were most pronounced in Kisat sediment samples than in Car Wash sediment samples. However, this variation was least pronounced in Car Wash water samples. This is probably due to variations in depths and perturbation. The Kisat area is rather shallow at 5 m than car wash area due to siltation from the Kisat river. Therefore PAH at 5 m distance in Kisat area are more susceptible to degradation than those from 5 m distance at car wash area perhaps because of greater aeration and higher nutrient concentration (WHO 1998). Water samples were taken at 1 m below the surface both at 5 and 10 m distances from the shore and therefore the PAH at these two distances were having equal photodegradation effects. The general slight increase in the mean concentrations between 5 and 10 m distances for water samples could be attributed to the fact that there is more disturbance of the PAH at 5 m distance by the waves than at 10 m distance from the shore. PAH generally adsorb to suspended particles in surface waters with the lighter hydrocarbons remaining in solution (Boehm 1987). Sorption of organic contaminants onto particles has been shown to depend not only on the particulate loading, but also on the types and degree of aggregation of the particles available. This is greatly influenced by the wave disturbances. The lipid particles onto which PAH are more adsorbed are more dispersed in areas that experience higher disturbances (Dixon et al. 1987).

The concentration variations could also be attributed to distance and season interactions as these interactions showed significant differences ($p \leq 0.05$). This could be because there is less variation in mean concentrations as the distance increases in shore, even with seasonal variations. This observation may be attributed to dilution factor on the PAH concentrations which tends to become constant with increase in depths (WHO 1998). It is therefore possible that the dilution fate of the PAH is the most dominant factor making the sediments inshore to have relatively lower constant PAH concentrations. Most lower molecular weight PAH like naphthalene and acenaphthylene only showed significant differences 1 m from the shore and not 5 m from the shore for sediment samples, even with changes in seasons. This could be attributed to their being more soluble in water and therefore do not easily settle to the bottom of the water to get adsorbed to the sediments, hence only get in touch with the sediments at more shallow depths (Witt 1995).

Most higher molecular weight PAH like Chrysene and pyrene showed significant differences at 5 m distances from the shore with seasonal variations because they are less soluble and tend to settle at the bottom of the water where they get bound to the sediments (Witt 1995). The amounts that enter the waters during dry and wet seasons would therefore affect the amounts that get adsorbed to the sediments.

In the water samples, the lower molecular PAH such as acenaphthylene and acenaphthene did not show significant differences with distance, even with seasonal variations. This was also observed with higher molecular weight PAH like benzo(a)anthracene, chrysene and benzo(ghi)perylene.

This could be attributed to the fact that for water sample, dispersion in water for the PAH is usually very fast as a result of waves, and that solubility of the individual PAH would not change with season (Witt 1995).

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References

Baumard P, Budzinski H, Michon Q, Garrigues P, Burgeot T, Bellocq J (1998) Origin and bioavailability of PAHs in the Mediterranean sea from mussel and sediment records. Estuar Coast Shelf Sci 47:77–90

Boehm PD (1987) Transport and transformation processes regarding hydrocarbon and metal pollutants in offshore sedimentary environments. In: Boesch DF, Rabalais NN (eds) Long term effects of offshore oil, gas development. Pergamon, New York

David N, Nancy L (1995) Identification of pollution sources in the Kenyan part of the Lake Victoria catchment area. A Kenya-Belgiam joint project in Fresh Water Ecology. National Environmental Management Agency, Kenya

Dixon KL, Maki AL, Brungs WA (eds) (1987) Fate and effects of sediment-bound chemicals in aquatic systems. Pergamon, New York

Hostettler FD, Pereira WE, Kvenvolden KA, Van Green A, Luoma SN, Fuller CC, Anima R (1999) A record of hydrocarbon input to San Francisco Bay as traced by biomarker profiles in surface sediment and sediment core. Mar Chem 64:115–127

IARC (International Agency for Research on Cancer) (1983) IARC monographs on the evaluation of the carcinogenic risk of chemicals to human. Polynuclear Aromatic Compounds, Part I Chemical Environmental and Experimental Data. World Health Organization, Geneva, Switzerland

McVeety BD, Hites RA (1988) Atmospheric deposition of polycyclic aromatic hydrocarbons to water surfaces: a mass balance approach. Atmos Environ 22:511–536

Ogutu-Ohwayo R, Mugide R, Batirwa JS (eds) (2002) Technical guidelines for management of fisheries resources; Biodiversity and environment of Victoria basin Lakes. Technical document No. 1. Fisheries Resource Research Institute, Uganda

Onuska FI (1989) Analysis of polycyclic aromatic hydrocarbons in environmental samples. In: Afghan BK, Chau ASY (eds) Analysis of trace organics in the aquatic environment. CRC, Boca Raton, Florida

Readman JW, Mantoura RFC, Rhead MM (1984) The physic-chemical specification of polycyclic aromatic hydrocarbons (PAH) in the aquatic system. Anal Chem 319:126–138

Simpson CD, Cullen WR, Quinlan KB, Reimer KJ (1995) Methodology for the determination of priority pollutant polycyclic aromatic hydrocarbons in marine sediments. Chemos 9:4143–4155

United Nations Environmental Programme (UNEP) (1992) Determination of petroleum hydrocarbons in sediments. Reference Methods for Marine Pollution Studies No. 20. UNEP, Monaco

Wakeham SG, Farrington JW (1980) Hydrocarbons in contemporary aquatic sediments. In: Petrakis C, Weiss FT (ed) Petroleum in the marine environment. ACS Advances in Chemistry Series No. 185. American Chemical Society, Washington, DC

Witt G (1995) Polycyclic aromatic hydrocarbons in water and sediments of the Baltic Sea. Mar Pollut Bull 31:237–246

World Health Organization (WHO) (1998) International programme on chemical safety. environmental health criteria 202. Selected non-heterocyclic polycyclic aromatic hydrocarbons. WHO, Geneva

Yunker MB, Snowdon LR, Macdoland RW, Smith JN, Fowler MG, Skibo DN, McLaughlin FA, Danyushevskaya AI, Petrova VI, Ivanov GI (1996) Polycyclic aromatic hydrocarbon composition and potential sources for sediment samples from the Beaufort and Barents Seas. Environ Sci Technol 30:1310–1320